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THE BLIGHTS OF CONIFEROUS NURSERY STOCK.

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INTRODUCTION.

There has been a good deal of complaint from forest and ornamental nurseries in various parts of the country of injury to conifers by blight. All cases in which trees in the nursery turn brown and die, in whole or in part, without any very definite symptom to indicate what caused death are classed as blight.

The damping-off diseases and those caused by the rust fungi, detailed descriptions of which may be found in a bulletin by Spaulding,[1] are not included under the name "blight." Damping-off attacks only very young seedlings, doing most of its damage during the first three weeks after germination. It is caused by several parasitic fungi which attack the soft tissues of the tender seedlings and rot them, often entirely destroying great numbers of plants in a few days. Unfortunately one of these fungi sometimes continues to kill seedlings for a time after they have become older and tougher, so that they look more as if they had been killed by a blight than by damping-off.

Because of the difficulty in finding a natural dividing line between the damping-off diseases and the blights, it has become necessary to draw an arbitrary line between them. All parasitic death of seedlings less than 2 months old will be classed as damping-off. The reason for this classification will be presented under the heading "Root-rots." The present paper will consider as blights only diseases of stock more than 2 months old. Since the rust fungi are not common in our nurseries and make their presence known before the death of the plant by swellings of the stems and by the breaking out of orange-colored spore pustules, there should be no difficulty in dis-

[1] Spaulding, Perley. The blister rust of white pine. U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin 206, 88 p., 2 pl., 5 fig., 1911.

tinguishing between blights on the one hand and damping-off and rusts on the other.

Losses caused by blight are very considerable, nurseries not infrequently losing practically their entire stock of one or more species of conifers by blight attacks. In many of these cases both the cause of the attack and methods of preventing or stopping it have been entirely unknown. No systematic investigation of these blight attacks had been undertaken in this country. In studying the problem the writer since 1909 has visited 31 nurseries which raise conifers and has corresponded with many others. Many different types of blight have been found to exist. By his own observation and experimental work and by bringing together the information obtained from practical nurserymen and from the European literature on nursery diseases, the writer has succeeded in distinguishing quite clearly between the most important types of blight and drawing conclusions as to the best preventive measures. In the following pages the causes, distinguishing characters, and preventive measures for all of the types of blight met with are given as fully as the present condition of our knowledge will permit.

PHYSIOLOGICAL TROUBLES.

SUN SCORCH.

Sun scorch is the commonest and most serious trouble in most of the nurseries. By sun scorch is meant the death of entire seedlings or transplants or parts of them, due to lack of balance between the water absorption by the roots and water loss from the needles during the growing season. Stated in a somewhat simpler way, sun scorch is drought injury which occurs in the growing season. The term "sun scorch" has been used by Stone [1] and others for a similar trouble of conifers in New England forests. Its work in second-year seed beds on sandy soil has been described by Hartig.[2] It will be considered in detail, because in many cases it resembles other diseases so closely as to go unrecognized. For example, sun scorch for several years caused heavy losses in both seedlings and transplants at the Forest Service nursery at Halsey, Nebr., where most of the writer's work on this disease has been done. In a single case the records indicated a loss of 70 per cent of all the 2-year-old seedlings of jack pine (*Pinus divaricata* (Ait.) Gordon) and Scotch pine (*P. sylvestris* L.). The damage looked so little like drought that for some time it was supposed to be due to parasitic fungi, and Bordeaux mixture was employed to control it. Losses from this disease have

[1] Stone, G. E. Sun scorch of the pine. Massachusetts Agricultural Experiment Station, 22d Annual Report, pt. 2 [1909], p. 65–69, 1910.

[2] Hartig, Robert. Lehrbuch der Baumkrankheiten. Aufl. 2, Berlin, 1889, p. 104.

occurred at nurseries in Colorado, Minnesota, Pennsylvania, and New York without being recognized by the nurserymen.

HOW SUN SCORCH WORKS.

In serious cases of sun scorch, seedlings of all ages are killed outright. In less serious cases part of the plant is killed. Either the tips or the lower needles may be first affected. If the tips are injured, stem and bud may be killed as well as the needles, so that growth can be resumed only by lateral buds below the point of injury. In slight attacks only the needles, and often only the tips of the needles, are killed. When the lower needles are the only ones attacked, despite the fact that they are well protected from sun and wind in dense stands, it must be assumed that the younger needles at the tips, subjected to much more light and wind, have survived at the expense of the lower ones by taking more than their share of the available water. Affected needles first turn slightly yellowish, lose their green until they have become a pale straw color, and then gradually turn deeper brown until they become nearly red. In summer most dead needles fall within a month.

In crowded seed beds, especially on very sandy soil, attacks may take place very suddenly in hot, dry weather, and patches of seedlings up to a foot in diameter may be entirely killed. It is these definite, clean-killed patches which have most often caused the disease to be called parasitic. Such even death can be explained on a drought basis only by assuming that in such cases the root systems of all the seedlings involved have been equally extended in normal competition for water, just as the tops often grow to an exactly even height in competition for light, so that all the seedlings in the patch are on terms of equality when the competition becomes critical. When part of the seedlings in a crowded bed are badly suppressed the smaller seedlings are in some cases, when transpiration is rapid, even less subject to sun scorch than the larger. Since the suppressed seedlings presumably have less extensive root systems, their endurance in such cases must be explained by the fact that they are also less subject to water loss because of the protection afforded by the tops of the larger plants around them. When the beds are not crowded and the weather does not favor extremely rapid water loss, death does not occur so suddenly or in such definite patches.

In the cases of transplants a certain number die soon after they are set out and before root growth starts. This has been called "transplanting loss" and is not included under the term "sun scorch." "Sun scorch" is used in transplants for death due to excessive water loss after the plants have become partly established and commenced growth. The work of sun scorch in transplant beds at Halsey differs from that in seed beds in that the trouble in the transplants does not

occur in such distinct patches; and if any part of a transplant is affected, either an entire branch or the entire plant dies at once.

A feature of sun scorch in nurseries, as well as in the older trees described by Stone,[1] is that the absorbing portions of roots die at the same time as the tops or even before. This indicates that the leaf and stem tissues can stand water loss better than the vegetative tissues of the roots. Especially in the case of transplants the cambium of the entire root system, or at least of the outlying portions of it, has been found to be dead and brown. By the time the needles show the first signs of yellowing, a large part of the root cambium is already gone. This especially early death of a large proportion of the root systems of the scorched transplants is probably due to the fact that a tree in the transplant bed has a smaller root system in proportion to its transpiring surface than a second-year seedling would have. When only a part of the needles on a plant are killed it appears that the damage to the root is more extensive than to the tops. This is indicated by the fact that a plant which has lost part of its needles in an attack of this disease is more likely to succumb to later attacks of the same nature. Evidently the reduction in transpiring surface caused by the first attack is more than counterbalanced by the reduction in absorbing surface.

During several sun-scorch attacks at Halsey, and at two or three other times when the weather was hot and dry but no actual sun scorch had occurred, a peculiar type of injury appeared on young, growing shoots of second-year pine seedlings. White, shrunken, watery-looking patches appeared on the green stems rather suddenly, followed by the death of the plant beyond the point attacked. A very similar "white-spot" injury, occurring near the bases of the stems of seedlings less than a month old at the Halsey nursery, and which has often been confused with damping-off, can be controlled by shading and watering. While a parasite may be in some way concerned in causing the trouble in both ages of stock, there is little doubt that drought and possibly also excessive light or heat working independently are mainly responsible. This white-spot injury to second-year seedlings is included under sun scorch because it often occurs simultaneously and can be prevented by the measures which prevent scorch. It is not important.

EVIDENCE AS TO CAUSE OF SUN SCORCH.

The conclusion that the disease is due to disproportionate water loss is based on the following facts:

(1) Spraying with fungicides has failed to control the trouble. While spraying experiments have not been exhaustive, Bordeaux

[1] Stone, G. E. Sun scorch of the pine. Massachusetts Agricultural Experiment Station, 22d Annual Report, pt. 2 [1909], p. 65–69, 1910.

mixture, ammoniacal copper carbonate, and copper acetate were tested repeatedly during several seasons. Unfortunately for the experiments, little trouble with the disease occurred at the times when the fungicides were used. In four cases, however, the disease attacked parts of the nursery containing experimental plats which had been more or less recently sprayed with copper mixtures containing soap. In these cases there was no evidence that the fungicides afforded any protection. This lessens the likelihood that needle parasites are concerned in causing the disease.

(2) On sandy soil the attacks which most closely imitate parasitic injury by killing definite patches occur suddenly and often simultaneously in many parts of the nursery. Serious damage may appear through thousands of square feet of seed beds inside of 48 hours from the time the first evidence occurs. This renders it unlikely that root parasites play any important part in causing the disease.

(3) The most typical attacks of the disease observed at Halsey occurred on days when wind and temperature were high and humidity low and following nights which had been unusually warm and without dew—conditions which favor excessive transpiration. This emphasizes the relation of transpiration to the disease.

(4) In general, the most trouble occurs during dry seasons. The larger commercial nurseries in Minnesota and Iowa report that the most serious trouble they have had was during the very unusually dry summer of 1910.

(5) Partial shade greatly decreases loss and entirely prevents trouble except in very severe attacks or during persistent drought. Shade was tested in five different attacks at Halsey in 1908, 1909, and 1910, and in all cases controlled or greatly lessened the losses, as indicated by the results in adjacent shaded and unshaded plats.

(6) Crowding strongly predisposes to the trouble. In the beds at Halsey the seedlings at the margins which have sent their roots out into the unoccupied paths are practically never attacked, though in some cases the entire interiors of beds have been killed. This immunity of the edges of the beds is more marked on sandy soils than on heavier ones.

(7) Attacks of the disease regularly occur when the soil is very dry. Very sandy soils, which are more quickly reduced to a low water content, are the commonest locations for the disease. In two different attacks at Halsey direct comparisons were made of soil moisture in diseased and relatively healthy areas, taking samples between the depths of 7 and 11 inches, where the greatest mass of absorbing roots lay. In one case the samples from the four points tested in the healthy area showed an average water content 32 per cent higher than that of the two points taken in the blighted stand adjacent. At the time of the other attack four samples were taken

from the blighted area and two from the healthy, and determination showed 30 per cent more water in the samples from the healthy area. Altogether, samples taken at 10 different points in diseased stands during three different attacks gave an average moisture content of 3.4 per cent for the soil from 2 to 11 inches in depth. The average wilting coefficient of the soil at this nursery, determined from samples taken from the same depths at nine different points located in the same parts of the nursery as the moisture determinations above referred to, was 3.6 per cent, as determined by the indirect method of Briggs and Shantz from moisture-equivalent determinations made by the Laboratory of Biophysical Investigations. While the soil-moisture determinations made were too few to establish the relation of dry soil to the disease, they are to be viewed as contributory evidence.

(8) High points in beds and the centers of arched beds from which the water runs off or which are missed in flood irrigation are especially liable to damage from the disease.

(9) Species which normally inhabit moist soil suffer most. Norway spruce (*Picea excelsa* Link) and Douglas fir (*Pseudotsuga taxifolia* (Poir.) Britt.) seem to suffer oftener than the pines. Western yellow pine (*Pinus ponderosa* Lawson) grown from Rocky Mountain seed is more resistant at Halsey than other pines.

(10) Sufficiently frequent and heavy watering will entirely prevent the disease. In three different attacks at Halsey evidence of the preventive effect of watering was obtained. The main practical fact is that for two seasons the nurserymen at Halsey and at Monument, Colo., have practically controlled the disease by increasing the frequency of watering. At these nurseries during the three preceding seasons the disease had caused considerable loss. At both these nurseries the disease had been considered parasitic.

It is not thought that death is usually due to the entire lack of available soil moisture. It is rather probable that it usually occurs when there is still a certain amount of available water left in some part of the soil reached by the root system, but so small in quantity that it can not be taken up by the roots fast enough to supply the demands of the rapid transpiration loss from the needles. This does not necessarily mean slowness of imbibition; it may simply mean that the capillary water movement from outlying soil particles to the particles adjoining the root surface is too slow when the soil is nearly dry. That this is the case is indicated by the fact that after an attack of sun scorch has started as the result of one or two days of rapid transpiration, when the soil is quite dry, the disease may stop spreading on the advent of cooler weather without the addition of any water to the soil from above.

Some interesting occurrences at Halsey in connection with this trouble, which at first appeared to contradict the relation of the dis-

ease to water loss, may be mentioned. Losses have frequently been more serious in the nursery transplant beds than in the trees planted out in the sand hills, where there is little humus and no wind protection and where no artificial watering is done. This was advanced as an argument against drought as a cause of the trouble. The fallacies in this argument are that the trees used in the hills had been previously once transplanted, so that they were stronger and better rooted stock, and that in the hill plantations there was not so much competition as in the transplant beds, where the close stands of trees exhaust soil moisture very rapidly.

Another argument against drought as a cause of the disease was the fact that in certain cases the blight appeared at Halsey when the soil 2 or 3 inches down seemed quite moist. However, further examination and quantitative determinations of moisture content showed that at such times the soil around the mass of absorbing roots is drier than the soil near the surface. The dense stands of seedlings apparently exhaust the soil moisture at the lower levels more rapidly than evaporation takes the water nearer the surface.

A further argument advanced against the drought theory is the fact that at Halsey trouble often occurs within a very few days after fairly heavy rains. This happens, however, only in very drying weather and in beds where the stand is dense. Under such conditions the moisture is drawn from the sandy soil very rapidly, so that in all such cases the soil around the roots is found to be very dry despite relatively recent rains.

One case of sun scorch occurred at Halsey in 1910 which was quite difficult to explain, although the evidence presented by adjacent plats, some of which had been shaded and some especially watered, left little doubt as to its relation to drought. On July 25 and 26 a period of hot weather culminated in temperatures of 100° and 96° F., respectively. At about 7 a. m. July 27, 0.28 inch of rain fell. The sky cleared immediately after, the temperature rose to 102°, and the air became dry. July 28 was cool and cloudy. On that morning a large number of the smallest grade of 2-year-old jack-pine transplants had begun to turn yellow, and in 24 hours about one-third of all the stock of this class showed injury. Trees continued to turn yellow and die in decreasing numbers during three or four days of cool, partly cloudy weather following till the loss reached fully 50 per cent. The 0.28 inch rain of the 27th appeared to penetrate to the roots through the rather coarse soil. The best explanation seems to be that the roots were injured by the excessive demand on them during July 25 and 26, before the rain fell, or on July 27, before the rain had time to get down to the root level. The failure of the tops to show injury till some time after the roots are hurt is always more marked in transplants than in seedlings. There seems to be no rea-

son to think that the high temperature of July 27 injured the trees directly. While 102° F. is unusually high, the temperature has gone to 107° at this nursery without injury to the pines.

The death of the roots, especially characteristic of sun scorch in transplants, has led to the belief in some quarters that root parasites were the immediate cause of the disease. The evidence obtained contradicts this view. The most that can be said is that in many places some of the common soil fungi may act as facultative parasites, killing weakened portions of root systems and so making the plants somewhat less able to withstand drought injury. Even this has not been demonstrated, and from the nature of the case it is practically impossible to demonstrate it. An attempt was made to secure evidence on this point by carefully washing the roots of healthy 1-year-old jack-pine seedlings and planting part in autoclaved soil and part in untreated soil. All the soil used came from part of a bed at the Halsey nursery which had been affected with sun scorch. After the plants had had a few weeks to become established all the pots were allowed to dry out. Death occurred in a manner fairly characteristic of sun scorch, coming at practically the same time in both sterilized and unsterilized pots. Microscopic examination indicated about the same fungi in the dead roots in both sterilized and unsterilized soil. The results were entirely negative. Because of the impossibility of securing a growth of stock large enough to exhibit typical blight symptoms and of keeping any of it free enough from common soil organisms to use as controls for inoculation tests, there is little chance of learning anything definite as to what part fungi may play in causing sun scorch.

Taken as a whole, the evidence is believed sufficient to establish a lack of balance between water absorption and water loss as the chief, if not the only, cause of the disease. While there have at times been occurrences rather difficult to explain, 13 different attacks of the disease have been seen at Halsey, and in all of them evidence has been obtained of the relation of the trouble to drying weather, shade, crowding, or soil moisture, and in most cases to two or more of these factors. The Halsey nursery has been under fairly continuous observation by the writer during the summers of 1909, 1910, 1911, and 1912, and it can be said quite positively that all the serious losses which occurred in established stock over 1 year old during the growing seasons in this period could have been averted by maintaining sufficient soil moisture and mostly averted by shading. While the conditions are in many ways different from those at other nurseries, the evidence here obtained has been checked up by observations made at many other nurseries from the Rocky Mountains to the Atlantic coast. While some of the other diseases listed in this paper undoubtedly are concerned in the spring and summer losses at many

of the nurseries, the writer is confident that the largest proportion of the damage to pine, spruce, and fir nursery stock during the growing season can be classed as sun scorch.

HOW TO RECOGNIZE SUN SCORCH.

The best way to tell whether or not an attack of blight is due to sun scorch is to note the relation between the occurrence of the disease and crowding, shading, drying weather, sandiness of soil, lack of soil moisture, and drought resistance of different species, as described in the foregoing paragraphs. The only characteristic of value shown by individual diseased plants is the simultaneous death of needles and root tissue. When the character of the trouble is still in doubt, final determination must rest with the nurseryman. The best method of doing this is to lay out small plats in the beds at different points in the nursery, giving some of them special shade and others regular, heavy watering. If at the next attack of blight these treated plats come out much better than the other beds near them, he can know that the trouble is sun scorch and treat it accordingly.

PREVENTIVE MEASURES.

The best and only absolutely certain way to prevent sun scorch is to water the nursery beds. When stock over two months old is watered it should be watered heavily. The great trouble with artificial watering is that it is usually not done thoroughly. Most of the water applied in sprinkling with the hose, as it is often done, evaporates from the surface without reaching the roots at all, so that even frequent sprinkling is of little value. At Halsey very crowded beds must be heavily watered oftener than once a week in the most drying weather to prevent all injury from sun scorch. With one exception there is no other nursery known to the writer where so much watering is necessary. The density of the stand and the character of the soil and climate must determine the amount of watering needed to prevent trouble. In some nurseries on rather heavy soil no preventive is necessary except in most exceptional drought years.

Objection has been made to much watering, on the ground that it can be expected to make stock less hardy and less able to survive transplanting. Observation of the work of the disease has suggested that the other extreme may also decrease hardiness. If the trees are allowed to become too dry, many which are not killed entirely and which may show little or no damage above ground appear to have enough of their root systems killed to decrease their chance for survival.

At the nursery at Halsey, Nebr., the beds are flooded with water obtained by a lift of a few feet from a river. At Monument, Colo.,

the beds are watered by large portable sprinklers fed from a mountain reservoir. Even with such excellent equipment much watering is expensive. Most of the commercial nurseries have very crude watering facilities and many of them none at all. At many nurseries putting in a watering system simply to prevent sun scorch would not pay. Indirect methods of controlling the disease are therefore of interest.

Shade frames of 2-inch slats, half an inch thick and spaced 2 inches apart, have proved a cheap and quite effective method of controlling the trouble at Halsey, though they do not prevent all loss. This slat shade was tested on July 26, 1910, at noon and at 4.20 p. m., with a photometer using "printing-out" paper. An average of eight determinations indicated that the shaded beds received 42 per cent of the amount of light received by unshaded beds at the same times of day. While this proportion must vary with the angle of the sun's rays, the average figure obtained is considered fairly representative for the period of most rapid transpiration. Therefore, the term "half shade," regularly used for this type of shade, while the best available, is not entirely accurate. When frames are only a foot above the ground, the slats should be placed north and south in order that all parts of the bed may get a reasonably uniform amount of shade. Shade put on after the attack has gone far enough to become noticeable can not prevent all injury, but may decrease it. In the cases of the successful use of shade seen by the writer the shades had been put on several weeks before the attack took place. Brush supported by rough frames 6 feet high is much used over all ages of seedlings by western commercial nurserymen and probably explains much of their relative freedom from sun scorch. Shade presumably keeps the beds from getting as dry as they otherwise would and at the same time enables the plants to live in drier soil than they otherwise could, by reducing the rate of transpiration loss from the needles. In growing stock for western forest planting, where it is difficult to secure survival, there appears the theoretical objection that shade in the nursery beds will make the stock more tender and harder to transplant successfully. Bates and Pierce[1] state that the half shade used at Halsey when kept over second-year seed beds has resulted in greater loss in the transplant beds the following year. They suggest gradually reducing the amount of shade on second-year seed beds. In the case of transplant beds it may be best to use the method tested in 1910 by Mr. C. R. Bechtle, formerly of the Forest Service. He erected rough temporary shade frames over the beds immediately after transplanting and removed them some weeks later when the trees had become partly

[1] Bates, C. G., and Pierce, R. G. Forestation of the sand hills of Nebraska and Kansas. U. S. Department of Agriculture, Forest Service, Bulletin 121, p. 32, 1913.

established. This method tends to protect the transplants during the period when they have the least absorbing root surface and exposes them to the sun during the larger part of the growing period, so that by the end of the season the trees should be thoroughly hardened and ready to stand field planting. Shade will always be a useful adjunct in preventing sun scorch, though the extent to which it should be used will vary greatly with different nurseries.

Crowding should be avoided in order to avoid sun scorch. What constitutes crowding varies greatly at different nurseries and with different species. At Halsey a second-year seed bed containing 75 Scotch pine per square foot is crowded. At Monument 150 Douglas fir per square foot do not crowd each other seriously at the same age. Transplants should be given much more room than seedlings. The older commercial nurseries often practice thinning in their older seed beds and generally give their transplants a great deal of space. Because of the extra cost of weeding and cultivating large areas and the limited space at some nurseries, it is sometimes probably cheaper to crowd stock in a small space and prevent scorch by increased shade or watering.

Extremely sandy soils should be avoided, and any deficiency in humus should be counteracted by manure and soiling crops, so as to increase the water-holding power of the soil. Nurseries on very sandy soils in the Northeastern States appear to have more trouble from sun scorch than western nurseries, which have drier climate but somewhat heavier soil. Windbreaks and surface cultivation are also undoubtedly helpful in preventing sun scorch.

WINTERKILLING.

Winterkilling is generally understood to mean death as a result of drying when the soil and roots are so frozen that the amount of water given off from the leaves can not be replaced to a sufficient extent by absorption from the soil. In this way its cause is fundamentally the same as that of sun scorch, the difference being that it occurs while the soil is frozen. Alternate freezing and thawing is considered important in bringing about damage. This may be due simply to the increased loss of water from the needles during warm periods which do not last long enough to thaw out the soil materially. In the West, the warm winds known as "chinooks" produce such sudden very warm periods in the midst of the coldest weather that not only small plants but even the largest forest trees are sometimes killed.[1]

[1] Hedgcock, G. G. Notes on some diseases of trees in our national forests. III. Phytopathology, v. 3, No. 2, p. 112–113, 1913.

Hartley, Carl. Notes on winterkilling of forest trees. Forest Club Annual [University of Nebraska], v. 4, p. 41–46, 1912.

The formation of ice crystals in the younger tissues at the close of the thaws may also be concerned in causing injury. Trees affected by winterkilling in the nursery look much like trees affected with sun scorch. Winterkilling can be distinguished from other types of blight by paying attention to attendant circumstances. The most damage may be looked for during the hardest winters or winters with little snow. It is likely to be worst where the beds are least protected by windbreaks or a mulch and in the least resistant species.

Winterkilling and sun scorch work differently in that winterkilling is worst in open stands, while with sun scorch the case is reversed. This may be explained not only on the ground that the closely sown trees protect each other from drying winds, but also, as pointed out by Forest Supervisor Elers Koch, act as a mulch, protecting the soil from deep freezing.

The ordinary measures for preventing winterkilling are to protect the nursery beds as thoroughly as possible by windbreaks and to mulch the beds with straw. Mulching must be done cautiously. It is likely, especially if heavy or close, to result in mulch injury and do more harm than good. Mulch injury is entirely different from winterkilling and will be considered later in this paper.

Heaving is also distinct from ordinary winterkilling. The roots of nursery stock in heavy soil are sometimes lifted partly or entirely out of the ground by the action of alternate freezing and thawing. Both plants and surface soil are raised by the expansion of the soil in freezing. In thawing, the soil settles back gradually around the roots, which are left higher than they were previously. The process is entirely mechanical. Like winterkilling, heaving can be prevented by mulch.

FROST INJURY.

Frost injury differs from winterkilling in that it is due to the formation of ice crystals in unripened tissue, while winterkilling is probably due mainly to drying out, as above described. In addition to injury to unripened tissue above ground by early frosts, it is possible that early freezing of the soil injures by killing roots which have not yet stopped growth. According to Hartig,[1] trees with injured roots are likely to start growth the following spring before showing any effects and then turn brown rather suddenly. Very late spring seed sowing and encouraging the growth of stock toward the end of the season should be avoided, in order to get the tissues properly ripened up and able to endure freezing. Covering beds with a mulch before the first heavy freeze should prevent injury, though very early mulching must be avoided.

[1] Hartig, Robert. Text-book of the Diseases of Trees. Translated by William Somerville, revised and edited by H. M. Ward. London, 1894, p. 289.

Death from late frosts in the spring is rather frequent. Jack pine, because of its tendency to start growth very early in the spring, frequently loses its terminal buds and young shoots as the result of severe frosts after growth has begun, although these young, tender shoots are capable of standing a temperature considerably below freezing without injury. Douglas fir nursery stock in the West also seems to be quite susceptible to such injury. The use of some form of shade to delay very early growth, placing beds of susceptible species on high ground, and possibly the use of smudges, heaters, or a temporary straw or burlap mulch on nights when frost is feared, are methods which might be suggested for preventing spring frost injury.

EBERMAYER'S BLIGHT.

In Germany, Ebermayer[1] states that death in pine nurseries results from sudden warm weather in early spring when the soil is so cold that the roots are unable to absorb water normally and make good the transpiration loss. The process which he described differs from sun scorch in that it occurs oftenest on heavy soil and when the soil contains excessive moisture. It differs from winterkilling in that it occurs after the soil thaws. He states that the best method of prevention is to decrease the transpiration loss by means of shade in the early spring. This blight does not occur commonly in the United States.

DISEASES DUE TO PARASITIC FUNGI.

NEEDLE-CAST.

Lophodermium pinastri (Schrad.) Chev. causes the shedding or "cast" of pine needles in German nurseries and plantations. The disease is not known to occur in American nurseries, whatever may be the case as to the presence of a fungus, but it is nearly certain to make trouble in the future in moist localities. A brief account of the disease, compiled from various statements of the great number of European writers on the subject, will therefore be given.

The disease has been known in Germany for more than a century under the name of "schütte." The causal relation of the parasite was first reported in 1852,[2] but was not established till some years later. When the parasitism of the fungus was established some writers apparently accepted it as the only cause of blight, while others, notably Ebermayer, who regarded physical factors as the com-

[1] Ebermayer, Ernst. Die Physikalischen Einwirkungen des Waldes auf Luft und Boden. Bd. 1, Berlin, 1873, p. 251–261.

Zur Schüttekrankheit der Kiefer. Allgemeine Forst- und Jagd-Zeitung, Jahrg. 77, p. 309–314, 1901.

[2] Göppert, H. R. [Hysterium pinastri als Ursache der Schütte.] Verhandlungen, Schlesischer Forst-Verein, 1852, p. 67.

monest or only cause of blight, criticised the parasitic theory of the disease. The fungus now seems to be generally accepted as the commonest cause of the blight of pines in German nurseries,[1] though it is recognized that other factors may also cause blight. Because of the confusion arising from the controversy mentioned, the term "schütte" has often been made to cover indiscriminately all forms of blight. It seems to the writer that the best policy will be to restrict the English equivalent term, "needle-cast," to the damage done by *Lophodermium pinastri*.

In Germany infection is said to take place between the end of July and the middle of September. The first reddening of isolated needles occurs in late September. In a very late fall the needles may turn brown and mature Lophodermium fruits appear before winter. Ordinarily the disease works very slowly during the fall and winter and rapidly in March and April. By May, in severe attacks, scarcely a green needle remains. Even with practically all the needles killed, the weakened plants are frequently able to resume growth at the terminal bud, though diseased trees are less able to survive transplanting than those not attacked. In some cases the parasite in the infected needles is said to enter the stem and kill it also.

The juvenile needles formed during the first year persist for a long time after death, while needles of the mature sheathed form are shed soon after death as a result of the formation of a cork separation layer. It is this early shedding of diseased needles which gives rise to the name of the disease. Spermatia are first formed on the fallen needles. By the end of July mature ascospores appear, capable of infecting healthy needles and thus completing the life cycle of the parasite. It is not certain that in this country the life history of the fungus would be the same as has been described for Germany. Some of the confusion concerning etiology that has increased the difficulty of separating needle-cast from other troubles can be traced to the fact that Ebermayer's blight, as well as death of roots from early fall freezing, may presumably cause the rapid death of the plants in early spring.

In needle-cast and related needle diseases the following characters may be expected:

(1) The first indication of disease in the needles will be the appearance of light brownish green spots. These will not be as likely as most of the physiological diseases to attack the tips of the needles first.

(2) Ordinarily the needles on any one part of the plant will not all die at the same time.

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[1] Haack. Der Schüttepilz der Kiefer. Zeitschrift für Forst- und Jagdwesen, Jahrg. 43, Heft 4, p. 329–357, pl. 4; Heft 5, p. 402–423; Heft 6, p. 481–505, 1 fig., 1911.

(3) Even when all of the needles die at nearly the same time, there will not be the simultaneous death of the roots which occurs in sun scorch.

(4) There will not be the same relation of the disease to dry weather and dry sandy soil as in sun scorch.

(5) Beds which have been protected by fungicidal sprays will not be so likely to be attacked as others.

In Germany needle-cast is said by Stumpff[1] and others to be controlled by spraying with Bordeaux mixture in July and August. There is no guaranty that the same measures will be effective in this country. If the disease makes serious trouble in any American nurseries, spraying at different times of the year should be tested, using the 4–4–50 or 6–4–50 Bordeaux mixture containing 2 or 3 pounds of soap per barrel.

Ebermayer has attacked the evidence supporting the parasitic origin of needle-cast, saying, among other things, that Bordeaux mixture may protect not by preventing the entrance of fungi so much as by decreasing transpiration. The writer's experience with the 4–4–50 soap-Bordeaux mixture may be of interest in this connection. A heavy application a short time before the occurrence of an attack of sun scorch in seed beds of *Pinus divaricata* at the Halsey nursery had not the slightest effect in decreasing the loss from sun scorch, as shown by a comparison of parallel sprayed and unsprayed beds. The shade afforded by a "half-shade" slat frame in one of these beds at this time gave absolute protection against the disease. This indicates that the effect of Bordeaux mixture in reducing transpiration at critical times is negligible.

PESTALOZZIA NEEDLE BLIGHT.

Pestalozzia funerea Desm. is very common in dead coniferous needles in the United States. Tubeuf[2] considers it the probable cause of a twig-blight of cypress trees. In the United States, Spaulding[3] induced needle disease on seedlings of *Pinus ponderosa* one month old by spraying with spores from a pure culture of this fungus. A test by the writer on 1-year-old white pine (*Pinus strobus* L.) under moist-chamber conditions, using cultures from jack and Rocky Mountain yellow pines, was without result. A further test on 1-year-old stock by Dr. Spaulding also gave negative results. Attempts were made by the writer to infect green shoots on old trees of arbor vitæ (*Thuja occidentalis* L.), some of which had been injured by punc-

[1] Stumpff. Die Schütte und ihre Bekämpfung. Zeitschrift für Forst- und Jagdwesen, Jahrg. 32, Heft 11, p. 675–687, 1900.

[2] Tubeuf, Karl von. Diseases of Plants Induced by Cryptogamic Parasites. English edition by W. G. Smith. London, New York, and Bombay, 1897, p. 493–499.

[3] Spaulding, Perley. A blight disease of young conifers. Science, n. s., v. 26, No. 659, p. 220–221, 1907.

turing, or heating, or both. Viable spores from pure cultures recently isolated from arbor vitæ were used. No results were obtained. While the fungus is presumably parasitic in nurseries under some conditions, the amount of damage it has caused is unknown. Spraying with fungicides before infection takes place should prevent damage by it.

OTHER NEEDLE DISEASES.

Various fungi which have been very little studied in this country cause needle diseases in American forests. Though none have yet been reported as causing disease in our nurseries, there can be little doubt that some of them have made, or at least will soon make, trouble in nurseries in this country. Much of the comparative freedom from needle diseases of American nurseries, even those in the more moist regions, has probably been due to the fact that most of our nurseries are not in forests. So far as needle diseases are concerned, it will be best to avoid forests of the same species as will be grown in the nursery in choosing sites for new nurseries. Of the fungi mentioned in the literature on needle diseases, which is mainly European, the following species will especially bear watching: *Lophodermium macrosporum* R. Hrtg. on spruces, *Lophodermium nervisequium* D. C. on firs, *Lophodermium laricinum* Duby on larches, and *Lophodermium brachysporum* Rostr. on white pine. *Lophodermium brachysporum* has been reported by Spaulding[1] as parasitic on needles of young white pines in Maine. Other species of this genus and species of Hypoderma and Sphaerella are also likely to prove more or less parasitic. It is probable that there are parasitic strains of needle fungi in foreign countries which if brought into this country will damage our nursery stock more than any of the fungi we now have. No practicable quarantine or inspection system will be able to keep out these diseases entirely. Nurserymen should avoid bringing in foreign pests by using home-grown stock as far as possible. So far as is now known seed may safely be imported, but bringing in growing stock should be discouraged.

The Atlantic seaboard and portions of the extreme western and northwestern sections of the country, where the climate is especially moist during parts of the year, are the most likely to suffer from needle diseases. In the Middle West, where atmospheric conditions are relatively dry, past experience indicates little trouble with needle parasites in unmulched beds. It is presumable that other needle parasites, like the one causing needle-cast, will be found to be preventable by spraying before infection takes place.

[1] Spaulding, Perley. The present status of the white-pine blights. U. S. Department of Agriculture, Bureau of Plant Industry, Circular 35, p. 10, 1909.

ROOT-ROTS.

Many soil-inhabiting fungi grow on dead roots of both seedlings and transplants. There undoubtedly are soil fungi which can kill living roots when conditions are favorable. A species of Fusarium[1] is said to have caused loss by killing pine roots in a Vermont nursery. Mycelial growth on roots, such as is there described, has been frequently observed by the writer, though in only part of the cases was it associated with any apparent injury to the plants.

Rhizoctonia sp. (probably *Corticium vagum* B. and C.), which causes damping-off of very young seedlings, sometimes continues to work in patches till the seedlings are 2 months old or even more. On sandy soil, when seedlings from 5 to 9 weeks old are killed, the youngest and deepest parts of the roots are usually first attacked. At Halsey roots of Rocky Mountain yellow-pine seedlings about 7 weeks old have been attacked at points as much as 11 inches below the ground surface. In many seedlings as old as this the older parts of the roots resist the entrance of the fungus which has rotted the younger parts and throw out new root branches, so that recovery takes place without any evidence of the damage being shown by the plant above ground. While we ordinarily consider damping-off as the death of very young, succulent seedlings, the killing of seedlings from 5 weeks to 2 months old by Rhizoctonia is merely a continuation of the earlier and more typical damping-off and to a certain extent is influenced by the treatments which control the early damping-off. For practical purposes, therefore, only the relatively small number of cases of root-rot which occur after the plants are 2 months old are considered as blight; root-rot of stock less than 2 months old is classed as damping-off.

Root-rot of stock more than 2 months old does not appear to have become a serious source of loss in this country. Until more is learned concerning it nothing of value can be said as to characteristic symptoms or control measures.

UNCLASSIFIED DISEASES.

STEM GIRDLE.

In Wisconsin, Oregon, Colorado, and New Mexico the stems of 2 and 3 year old conifers in nurseries have been found constricted or girdled in a peculiar manner just above the ground line, and sometimes abnormally large just above the point of girdling. The bark at the point of constriction is dead and often loose. The trees may continue in apparently good health for some time after the girdling.

[1] Gifford, C. M. The damping off of coniferous seedlings. Vermont Agricultural Experiment Station, Bulletin 157, p. 149–151, 1911.

but at length gradually become yellow and die. Scotch pine, Rocky Mountain yellow pine, white fir (*Abies concolor* (Gord.) Parry), Douglas fir, and Norway spruce have been found affected, the latter most seriously. A very similar trouble is known in Germany under the name "Einschnürungskrankheit." It is figured by Tubeuf.[1] Various coniferous and broad-leaved species are affected, beech, fir, and spruce being most prominently mentioned. In Germany *Pestalozzia hartigii* Tub. is found on the constrictions and is considered to be the cause of the disease. The causal relation has not been proved by inoculation, despite extensive experiments by Fischer.[2] Of the few cases of disease observed by the writer the fungus has been found fruiting on the lesions in a single case on Rocky Mountain yellow pine from New Mexico. In this case the bark had been dead so long that it had become loose. While the stem girdle in this country may be due to *Pestalozzia hartigii*, proof is lacking.

The important practical facts are that the disease does not often do serious damage, and that the only method of combating it which can be suggested is to destroy all diseased material. All girdled trees with bark killed entirely around the stem are certain to die and should be pulled out and burned at once without waiting for them to turn yellow.

MULCH INJURY.

In nurseries where beds are covered with a mulch during the winter to prevent heaving or winterkilling, heavy losses sometimes occur while the mulch is on the beds or just after it is taken off. While mulch injury usually occurs during the winter it is an entirely different thing from the winterkilling in unmulched beds. The general experience of nurserymen has been that the disease was worst where the mulch was heaviest, or where it was composed of fine material which packed down into a close covering. While the injury is the result of the use of mulch, the immediate cause of death is unknown. While physical factors may be entirely responsible, it is quite likely that death is due to some needle parasite whose work is favored by the conditions which prevail in mulched beds. What is very likely the same trouble occurs occasionally under a light mulch, or even under no mulch at all, when there is heavy or very late snow.

In two cases the writer has had opportunity to examine injured white-pine and Douglas-fir seedlings shortly after the mulch was removed. In both bases the roots were still healthy despite the death of the needles and in many plants of the upper parts of the stems.

[1] Tubeuf, Karl von. Diseases of Plants Induced by Cryptogamic Parasites. English edition by W. G. Smith. London, New York, and Bombay, 1897, p. 492.

[2] Fischer, C. E. C. Note on the biology of *Pestalozzia hartigii*, Tubeuf. Journal of Economic Biology, v. 4, No. 3, p. 72–77, pl. 7, 1909.

This survival of the root after the death of the top distinctly separates this trouble from those of the root-rot and sun-scorch types. The experience of a number of nurserymen shows that the disease can nearly always be prevented by using only loose, light material to mulch with and mulching no more than is absolutely necessary. Spraying with Bordeaux mixture just before the mulch is put on is worth a test at any nursery where mulch injury is frequent.

RED-CEDAR BLIGHT.

In western nurseries where red cedars (*Juniperus virginiana* L. and *J. scopulorum* Sarg.) are grown for ornamental planting there is a great deal of trouble with a blight of unknown origin. A number of nurseries have nearly or entirely stopped trying to grow cedar on this account. The disease is described as sometimes working suddenly over a considerable area of seedlings and transplants. Since attacks are said to occur when adjacent pines are perfectly healthy it is not likely that sun scorch is responsible. In large transplants all the needles on specific twigs and branches die at once, indicating a parasitic twig blight. In the cases observed by the writer there was no evidence of any constriction of the twigs such as Tubeuf[1] has figured for *Pestalozzia funerea* twig-blight on *Chamaecyparis menziesii*.

So little is known concerning the trouble that no recommendations for its control can be made. It is suggested that the nurserymen who have the most trouble with the disease conduct experiments separately with watering, moderately heavy shading, and frequent spraying with soap-Bordeaux mixture on numerous small-scale experimental plats scattered through their beds. One of these methods should prevent or partly prevent the disease. A comparison of attacks on treated and untreated plats should give information both as to the nature of the disease and the best control method.

MECHANICAL ROOT INJURY.

It often happens that trees which die in the nursery can be pulled up very easily. Examination shows that the root has been either broken or eaten off 1 to 3 inches below the surface of the soil. This presumably is done by grubs. This type of loss is mentioned merely to keep it from being confused with any of the types of blight described in this paper.

CONCLUSION.

A number of different blights concerning which little has been known do considerable damage to conifers in nurseries in the United States. The increasing amount of forest planting and the danger

[1] Tubeuf, Karl von. Loc. cit.

that imported stock will bring in serious tree diseases make it especially important that methods of controlling these blights be found, in order to encourage the growing of planting stock in this country. The writer has not only experimentally determined the cause and distinguishing features, but also the control methods for sun scorch, the most serious of these blights, and by following his recommendations the disease has been controlled in nurseries where it had before done serious damage. Distinguishing characters and preventive measures for the two other commonest blight types, winterkilling and mulch injury, have also been determined. An account of what the writer has been able to learn from his own work and the experience of others with the other types of blight is also given. Distinguishing characters and control methods have not been found for all of the types.

It is seldom that a case of nursery blight can be diagnosed merely by examining a few specimens of diseased trees. It is hoped to carry this investigation so far that each nurseryman will be able to identify for himself, by general observations, all of the types of blight which attack his nursery beds and to take the necessary steps for preventing further losses.

The writer wishes to acknowledge his indebtedness to Mr. W. H. Mast and Mr. R. G. Pierce for their cooperation in the work at the Halsey nursery, to Dr. H. L. Shantz for helpful advice, and to Dr. Perley Spaulding, under whose general direction the work was conducted, for advice and the use of his specimens and unpublished data.

SUMMARY.

The following are the types of blight most likely to cause losses of coniferous nursery stock in the United States:

(1) *Sun scorch.*—This is the commonest summer trouble. The roots die before or at the same time as the tops. Death is caused by excessive water loss. It usually occurs when the air is hot and dry and the soil around the roots is dry. The disease is worst on sandy soils, in crowded beds, and on raised parts of beds. On sandy soils it may kill suddenly and in definite patches. Successful preventive measures tested by the writer are watering, shading, and avoidance of crowding. In nurseries located on mineral soils the humus content should be increased.

(2) *Winterkilling.*—The tops of the plants dry out when the soil is frozen so that the plants can not take up water. The preventive measures most used consist of a light straw mulch on the beds and windbreaks.

(3) *Mulch injury.*—The tops die in winter as a result of being mulched. This happens while the mulch is still on, or occasionally

just after it is removed. The roots do not die till some time after the tops. The immediate cause of death is unknown. The disease may be prevented by avoiding heavy, close mulches. Spraying with soap-Bordeaux mixture just before the beds are mulched in the fall may also be of value.

(4) *Needle diseases.*—There are a number of needle-destroying fungi, some of which are certain sooner or later to cause damage in the nurseries in the more moist parts of the United States. They have so far done little damage in our nurseries and have been little studied. Spraying with Bordeaux mixture at the proper time will presumably prevent damage from any of them. The proper times for spraying are not yet known. The importation of European stock should be discouraged, in order to avoid bringing in parasites which have not yet reached this country.

(5) *Red-cedar blight.*—A great deal of blight occurs in red-cedar seedlings and transplants. The cause and methods of prevention are unknown. Shading, watering, and frequent spraying should be tested.

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